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ABSTRACT

An important new aspect of the space sciences is the associated field of reliability. The largest part of this effort on a space flight project is environmental testing. This paper presents, as an example, the successful environmental test program of the International Satellite Ariel II. Several specialized tests and unique techniques were employed to assure the quality necessary to accomplish the spacecraft mission. Valuable background information is provided on the mission, technical description, and launch of Ariel II. United Kingdom scientists have received data from more than 5000 orbits on: (a) galactic noise in the 0.75 to 3.0 Mc region, (b) the vertical distribution of ozone in the earth's atmosphere, and (c) micrometeoroid density.

BACKGROUND INFORMATION

International Satellite UK-2/S-52, or Ariel II as it is known now after injection into orbit, is the second in a series of three satellites of a cooperative United States-United Kingdom program.

On March 27, 1964, the four-stage Scout launch vehicle placed the Ariel II into an elliptical orbit (see frontispiece) ranging from 157 nautical miles at perigee to 730 nautical miles at apogee. The inclination was 51.66 degrees, and period was 101.37 minutes. This was the first international satellite to be orbited by Scout from Wallops Island, Virginia. It was the third international satellite.

British scientists in university and government laboratories designed and constructed the instrumentation for the Ariel II experiments.

The Goddard Space Flight Center, for NASA, had overall U.S. responsibility for the program, including design, development, construction, tracking, and data acquisition. The Westinghouse Electric Corporation, Aerospace Division, designed and manufactured some of the spacecraft subsystems and was responsible for integration of all of the subsystems into an operating spacecraft.

TECHNICAL DESCRIPTION

The Ariel II spacecraft is shown in Figure 1. Three quantitative experiments were included to accomplish the scientific investigation of certain phenomena in the atmosphere, the ionosphere, and beyond:

(1) The galactic noise experiment - to record galactic noise in the 0.75 to 3.0 Mc region and explore the ionosphere by noting its effect on the galactic noise measurement as the satellite penetrates the ionosphere during the closer part of the orbit.

(2) The ozone measurement experiment - to measure the vertical distribution of ozone in the earth's atmosphere by measuring the attenuation of solar rays as they pass tangentially through the atmosphere at twilight using wavelengths absorbed by ozone.

(3) The micrometeoroid experiment - to obtain quantitative measurements of particle flux.

Ariel II spacecraft is a 23-inch outside diameter cylinder at its center. End bells are spherical sections giving the main structure a length of 26.35 inches. Four solar cell paddles are mounted on arms secured to the aft end of the satellite structure. After ejection of the launch vehicle nose cone, four telemetry antennas in a turnstile array erect at equally spaced intervals. The two sensor booms and two inertia booms erect in a plane normal to the spin axis before the solar paddles deploy. At separation of the spacecraft from the fourth stage of the rocket, a long-wire galactic-noise antenna deploys 65 feet on each side, through the sensor booms, producing a 130-foot dipole normal to the spin axis. Another structural characteristic is the broadband ozone detector (approximately 2 inches in diameter and 9 inches high) centered atop the satellite.

The power supply consists of nickel-cadmium batteries that are rechargeable by solar cells. Telemetry is transmitted in two modes. Continuous real-time transmission of the galactic noise experiment and micrometeoroid experiment is Mode No. 1 or normal condition. The exceptions are:

(1) The telemetry switches to Mode No. 2 during a period of six minutes at each satellite sunrise and sunset. Data from the scanning ozone spectrometers is transmitted in real time, while data from the broadband ozone detector is recorded.

(2) Upon command, low-speed (real time/48) data from the ozone and galactic noise experiments, stored in the tape recorder, is transmitted at 48 times the recorded rate, giving the same bandwidth characteristics as real-time transmission.

The telemetry transmitter operates in the 136-137 Mc band. PFM/PM emission is used. RF power output is 0.25 watt. The telemetry transmitter carrier signal is used for tracking purposes. UK-2 is tracked by the NASA STADAN tracking network. The command receiver operates in the 120-Mc region. It receives the ground station signal and initiates tape recorder readout.

ENVIRONMENTAL TEST PROGRAM

Environmental tests on the integrated spacecraft were performed at the facilities of NASA/Goddard Space Flight Center, Greenbelt, Maryland. Present at all tests were representatives of the three British experimenters and personnel from Westinghouse and Goddard. Tests on the subsystems, manufactured at Westinghouse, were conducted at Westinghouse prior to integration into the complete spacecraft.

The environmental test program for the Ariel II consisted of a realistic series of environmental exposures which simulated the mission profile applied to both prototype and flight spacecraft. The configuration and mounting arrangement duplicated the space flight systems as nearly as possible. The performance of the spacecraft under test was monitored either by the on-board telemetry or by means of special instrumentation.

The spacecraft was continuously evaluated as calibrated stimuli were applied to the scientific experiments. Failures were diagnosed and corrected as they occurred, thereby eliminating the "weak-links" and continuously upgrading the quality-level of the system. Upon completion of the expected life exposure or after accumulation of sufficient exposure to reduce the failure rate to a random level, the spacecraft was considered qualified.

One element contributing to the success of the program was the establishment of the environmental specification early in the project development cycle. This can generally be accomplished after the mission and vehicle have been selected. This gives the designer a specific and tangible goal to work toward. This also means that the environmental test must be valid and based on an intelligent and realistic interpretation of measured data. For the prototype system in which qualification of the design was the main objective, test levels were set at 1½ times the worst conditions expected in flight. Considerable time and effort has been expended to arrive at levels high enough to uncover latent faults, but low enough not to excite unrealistic modes of failure. Flight systems were tested for acceptance at the worst conditions expected, but which were compatible with the mission profile. This philosophy recognizes that some of the flight system's useful life is used up by these ground tests. Reduced longevity was considered a prudent tradeoff to ensure that infant mortality would not occur. Added confidence in the design and assurance that fatigue failures would not be critical was achieved by running the prototype system tests for twice the duration of the flight units tests.

The prototype unit was cycled through the test series for a number of cycles to establish failure modes and time-to-failure history. For example, in the vibration test, the expected measured-frequency range was covered for both prototype and flight units. The amplitude (g's) was set at the average +2 sigma (95% point) value where several measurements were available. This amplitude value was increased 50 percent for prototype units; and the duration was twice the flight unit value, which was based on approximate flight time or a sweep rate which would allow the resonant condition to achieve at least 95 percent of its peak amplitude. While application of this philosophy to the launch environment is fairly straightforward, there were some difficulties with the orbital environments, such as: space vacuum, solar simulation, and the $4^{O}K$ heat-sink of space.

The spacecraft was exposed to a test which permitted thermal balance of a predetermined part of the system under the best attainable vacuum conditions--which were 1×10^{-5} torr or better. The thermal-vacuum test was conducted for both the "hot" and "cold" calculated orbital temperature extremes. This temperature was arbitrarily raised and lowered $10^{O}C$ for the prototype units. The length of the test was set at a few days hot and a few days cold.

The space environments of meteorites and energetic particles are known to be particularly damaging; however, facility limitations precluded their use in the environmental test program. These effects were treated and allowed for on an analytical basis by extrapolation of test results on materials and components.

The environmental exposures were applied in a sequence consistent with major events in the mission profile, such as: pre-launch operations, launch, separation and injection, and orbital flight.

In addition, there were several tests of a specialized nature. Tests of this type included structural tests, shroud fit, nose-cone ejection tests, spacecraft separation, antenna and boom deployment tests, and experiment calibrations.

The formal Ariel II test plan covered five phases of testing:

(1) Special Procedures (Engineering tests):

(a) A Dynamic Test Unit for separation and despin sequence tests.

(b) An Engineering Test Unit for vibration survey and structural integrity.

(2) Design Qualification Tests of subsystems to demonstrate the design and manufacturing integrity of newly-designed equipment.

(3) Flight Acceptance Tests of subsystems to provide assurance of acceptability for inclusion in the flight spacecraft.

(4) Design Qualification Tests of the prototype spacecraft to verify satisfactory design margins of the integrated spacecraft under the various environments to which it may be exposed during its lifetime within an adequate margin of safety.

(5) Acceptance Tests of the flight spacecraft to discover any defects in material and workmanship and to provide information relating to the unique performance characteristics of the spacecraft.

The Design Qualification Tests of the prototype spacecraft consisted of:

Temperature
Humidity
Vibration (Figure 3)
Electrical Interference
Thermal-Vacuum (Figure 4)

Solar Simulation
Steady State Acceleration
Despin Sequence and Antenna Deployment

The Flight Acceptance Tests of the flight model spacecraft included Vibration and Thermal-Vacuum.

Figures 4 and 5 show the levels used for the Ariel II tests.

DISCUSSION

During these tests on the prototype spacecraft, fourteen subsystem malfunctions occurred which were classified as "questionable operation," and ten were classified as "failure"; three of the subsystems underwent design changes, four underwent repairs, and four were replaced with identical spare units.

Of the ten failures, two occurred during temperature tests, four occurred during vibration, three occurred during thermal-vacuum, and one failure was between exposures.

Comparing these malfunctions with the ones that occurred during the testing of the flight model, seven were classified "questionable operation" and only one was classified "failure." Remember there were fourteen "questionable operation" and ten "failure" on the prototype.

In addition, a noticeable change in appearance of the spacecraft took place as a result of the environmental testing. Figure 6 is a photograph of the prototype spacecraft during the early phases of the testing. Figure 7 shows the final configuration of the flight model. The two outstanding physical differences were:

(1) The addition of a conical structure at the top of the spacecraft to support the broadband ozone sensor.

(2) The addition of appropriately located white strips for thermal control.

Quality is assured in the spacecraft tested under Goddard specifications because of the philosophy of 100 percent testing. Every subsystem and complete spacecraft must demonstrate that it can successfully operate in the predicted environment.

The achievement of high reliability of a spacecraft requires an intensive effort and demands near perfection in materials, design, management, manufacture, assembly, test, and launch.

The accepted definition for reliability of a given system is the probability of performing the required functions under defined conditions for a specified period of time. Specific probabilities for space missions are difficult to assign. A goal of 0.95 is commonly used or stated differently; the risk of failure should not be greater than 1-in-20. The operation of a scientific satellite after it is injected into orbit depends on the mission requirements. The required functions consist of sensing some space characteristics, such as: solar radiation, energetic particle, or micrometeoroid, converting the characteristic to an electrical signal, encoding several such signals, and telemetering the encoded signal to earth. In addition, there are functional requirements for temperature, spin, and attitude control. The success or failure of these required functions are seldom either black or white.

Reliability is an attribute of a system which must be designed into it. Testing is a reliability tool, used to eliminate weak links and discover failure modes, thereby upgrading system quality.

Achieving confidence in the successful performance of a spacecraft poses a new type of reliability problem. A mathematical model, so successfully employed in missile systems while useful in highlighting critical system elements, provides little assurance for space systems. Spacecraft are one of a kind, virtually hand-built systems. At most, there are a prototype and two flight units available. There is no experience data or failure mode information. The spacecraft, as a system, is very complex, utilizing thousands of components; it extends the state of the technology both in design and fabrication.

The scientist should always consider the environmental stresses in the initial stages of his design, to assure that the equipment will survive and perform during the satellite's mission. The environmental test laboratory is the proving ground for his design. The design which successfully passes the rigors of a good environmental test program is the one that performs in space.

UK-2/S-52

INTERNATIONAL SATELLITE NO. 2

ARIEL II

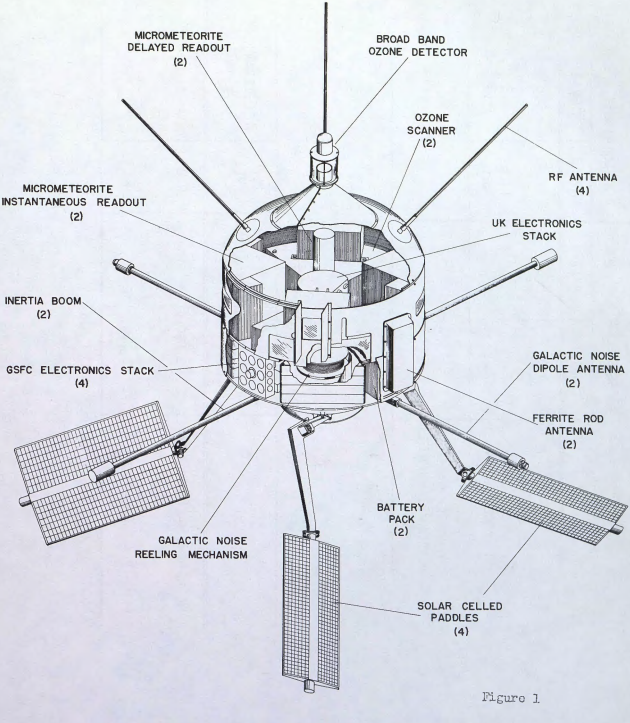

Figure 1

SATELLITE CONFIGURATION

SINUSOIDAL VIBRATION

FREQUENCY RANGE	DESIGN QUALIFICATION ACCELERATION, g's		FLIGHT ACCEPTANCE ACCELERATION, g's	
	THRUST	LATERAL	THRUST	LATERAL
5 - 50	2.3	0.9	1.5	0.6
50 - 500	10.0	2.1	7.1	1.4
500 - 2000	21.0	4.2	14.0	2.8
2000 - 3000	54.0	17.0	36.0	11.3
SWEEP RATE (OCTAVES/MINUTE)	2		4	

RANDOM VIBRATION

TEST	FREQUENCY RANGE (cps)	TEST DURATION (min.)	PSD LEVEL (g^2/cps)	ACCELERATION g - rms
DESIGN QUALIFICATION	20 - 2,000	4	0.07	11.5
FLIGHT ACCEPTANCE	20 - 2,000	2	0.03	7.7

NOTE: LEVELS ARE SAME FOR ALL 3 AXES

Figure 4

VIBRATION TEST LEVELS

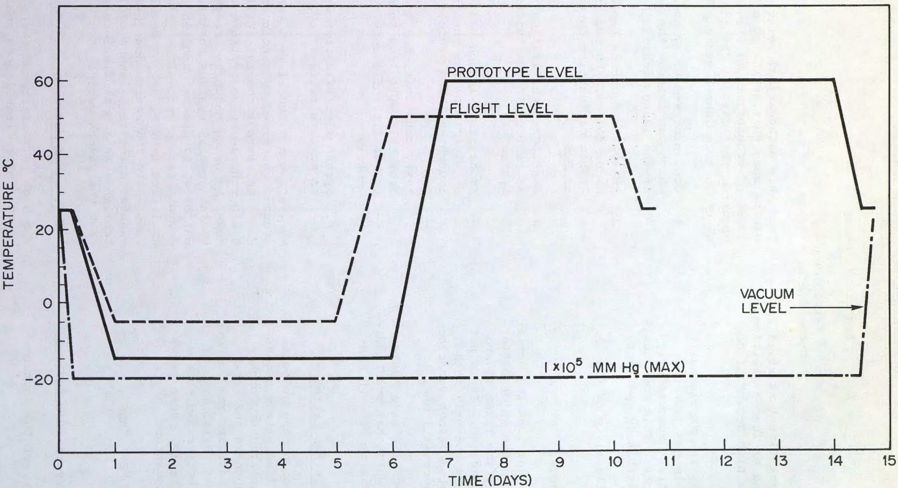

Figure 5

THERMAL-VACUUM TEST LEVELS